GPS PPS pulse timing uncertainity measurements, and noise measurements, using the Adafruit Ultimate GPS Breakout v.3

Cissy Wu, Cardozo High School
(mentors: Sam Resto and Prof. R. Armendariz)
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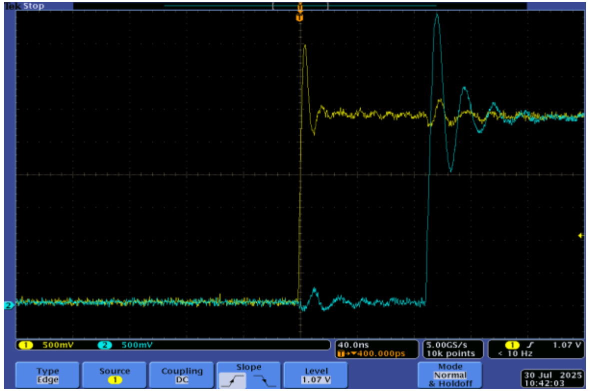
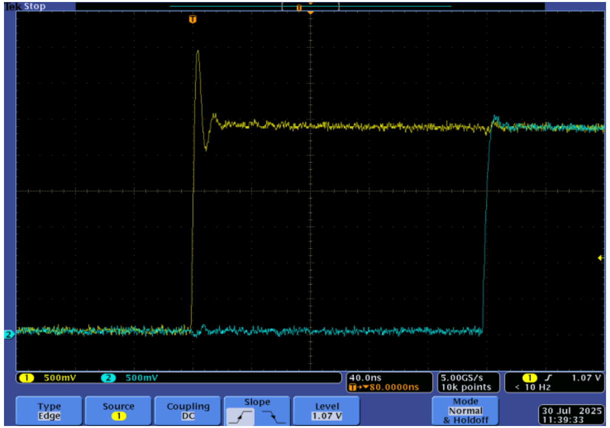
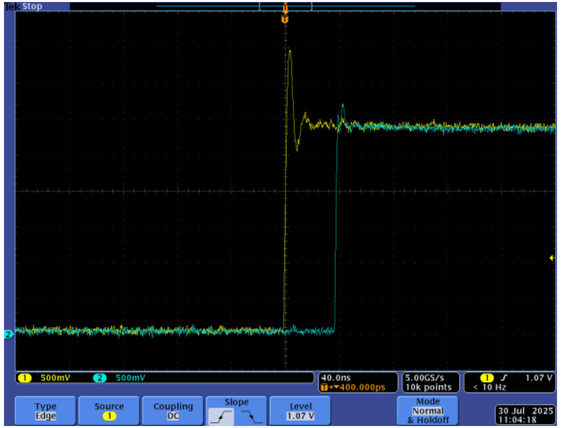
These are illustrative results for the GPS PPS pulse-timing and noise studies. Each plot shows the rising edges of two PPS pulses from two different GPS receivers. In the plots the pulses arrive to the oscilloscope between 40 ns to 200 ns apart (cable length differences only account for about 1 ns). The uncertainty on when a pulse would arrive to the oscilloscope varied with 300 ns being the worst case. The top plot shows voltage overshoots on both rising edges, followed by ringing oscillations on the low and high parts of the pulses; these are caused by impedance mismatch reflections, and made worse by RFI cross talk. The cross talk happens when placing two receivers side by side with unshielded PPS wires; notice when one receiver pulse goes high a ripple can be seen on the other pulse. The three plots below shows how the noise was eliminated. An edge trigger, and 1 MOhm terminations on both channels were used.

Module 3 (ch 1) 11.5 cm unshielded wire
Module 4 (ch 2) 32 cm unshielded wire

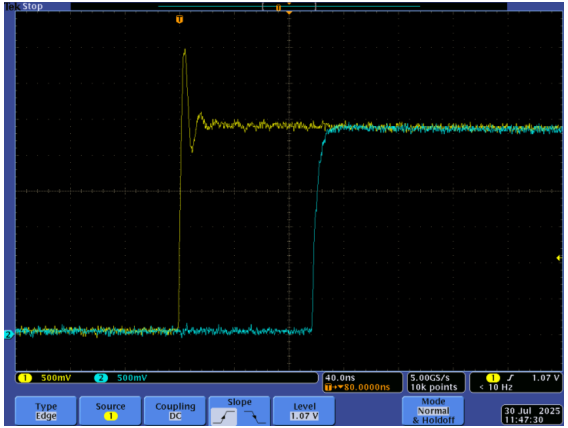




Module 3 (ch 1) 11.5cm unshielded wire.
Module 4 (ch 2) 100 Ohm resistor + 11.5 cm unshielded wire



Module 3 (ch 1) 11.5 cm unshielded wire
Module 4 (ch 2) 20 cm shielded wire



Module 3 (ch 1) 11.5 cm unshielded wire.
Module 4 (ch 2) 10 cm shielded wire with 100 Ohm resistor

Observations and Conclusions

Five GPS receiver modules were tested (numbered 1 through 5); module 3 was used as a control to trigger the oscilloscope.

Main results: the GPS PPS pulse arrival time varied from pulse to pulse, some receivers between +/- 20 to 60 ns, others +/- 100 to 200 ns, and the worst case was 300 ns. To eliminate noise, which significantly distorts the PPS shape and amplitude, short shielded wires (~ 21 cm are okay), and a 100 Ohm series resistor right after the PPS output were used.

The GPS PPS output impedance was measured to be 50 Ohms. GPS specifications say the PPS is supposed to output 3.3V high, but it consistently measured 3V across 1 Mega Ohm and 1.5V across 50 Ohms. The pulse goes high once per second and remains high for 100 msec. The rise time was measured to be 1.5 ns.

1. The time each GPS receiver's PPS pulse took to arrive to the oscilloscope typically varied by +/- 20 to +/- 60 ns from one pulse to the next.

2. The PPS pulse arrival times across different receiver modules varied with module 1's arrival time being the latest at 300 ns after module 3's.

3. After changing an antenna on a receiver its pulse arrival time took 130 ns longer; but we are unsure how much of this additional 130 ns is attributed to the antenna change because the pulse arrival time jumped around by +/- 20 to +/- 60 ns from one pulse to the next.

4. Latencies due to cable lengths using 50 Ohm coax: no latency was observed in the PPS pulse arrival time when a 50 ft cable was added between the antenna and receiver. A latency of about 1.5 ns per foot was measured when a cable was placed between the receiver PPS pin and oscilloscope; this is in agreement with the expected cable transmission time.

5. Two noise sources were identified:

i. A 1.2V overshoot to the PPS leading edge, and +/-1 V ripple appearantly caused by oscillations from an impedence mismatche. The GPS PPS appears to have a 50 Ohm output impedence as it measures 3V across 1 Mega Ohm, and 1.5V across 50 Ohms (because of the voltage divider). To remove the noise we placed a 100 Ohm resistor in series right after the PPS pin, in between the PPS and oscilloscope, and used 1 MOhm terminations on the oscilloscope channels so it measured the PPS at 3V. The 100 Ohm resistor tapers the 50 Ohm output impedence to the 1 MOhm input impedence, and prevents oscillations.

ii. Noise caused by radio frequency RF interference coupling onto the 11.5 cm unshileded jumper wires between the GPS PPS and oscilliscope. To prevent the RF noise we used a shielded wire between the PPS and oscilliscope, which we made 21 cm long to extend between the GPS and Arduino once placed in the DAQ box.

Two other ways we found that eliminate the noise:

a. Use a very short 3.5 cm length of wire from the PPS pin to the oscilloscope; this small wire has a round trip travel time of only about 1/10 of the PPS rise time, so the oscillation is faster than the PPS rise and does not interfere with the pulse. But it was difficult to connect such a short wire between them.

b. Match the impedence and prevent oscillations by using a 50 Ohm coaxial cable between the GPS PPS and oscilloscope, and a 50 Ohm termination on the oscilliscope; but we did not use this method because the voltage divider reduces the measured PPS to 1.5V.

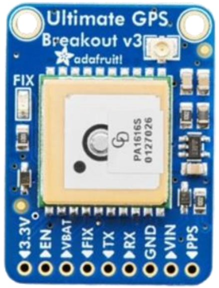
Hardware

Adafruit Ultimate GPS Breakout v.3
Used to send out pps (pulse per second) signals to the oscilloscope

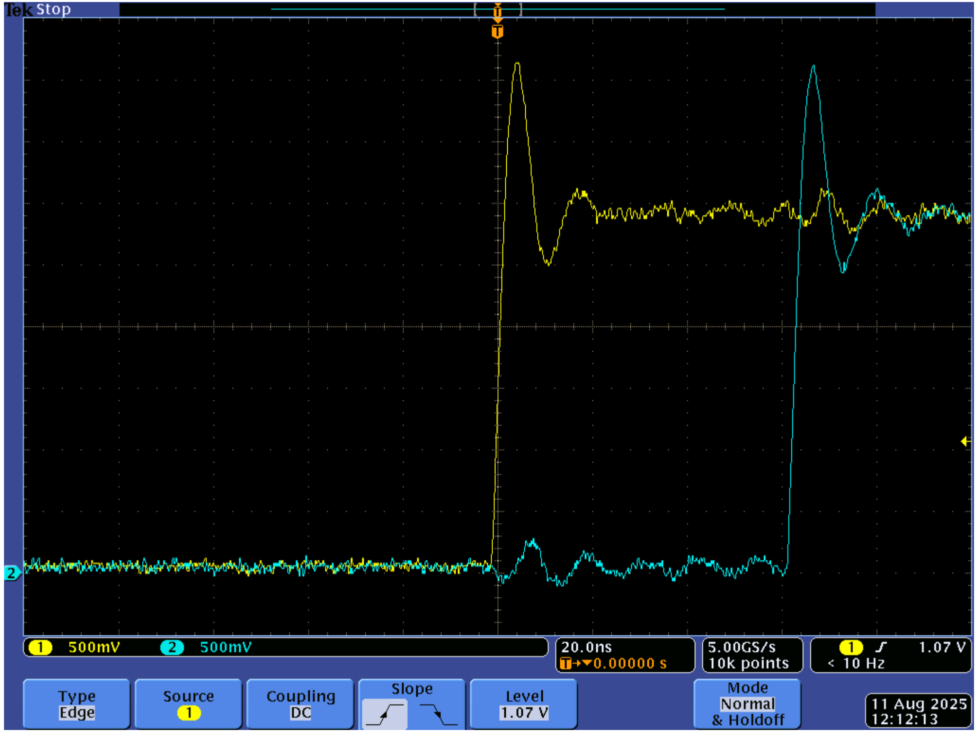
Arduino Mega 2560 was only used to power the GPS modules

Tektronix DPO4104 oscilloscopes
Display pps pulse signals sent from the GPS

Wires and Cables:
11.5 cm unshielded jumper wire
10 cm shielded wire
21.5 cm shielded wire
16 foot antenna-cable that comes attached to the antenna
50 foot RG58 shielded coax cable
30.75 inch RG58 shielded coax cable

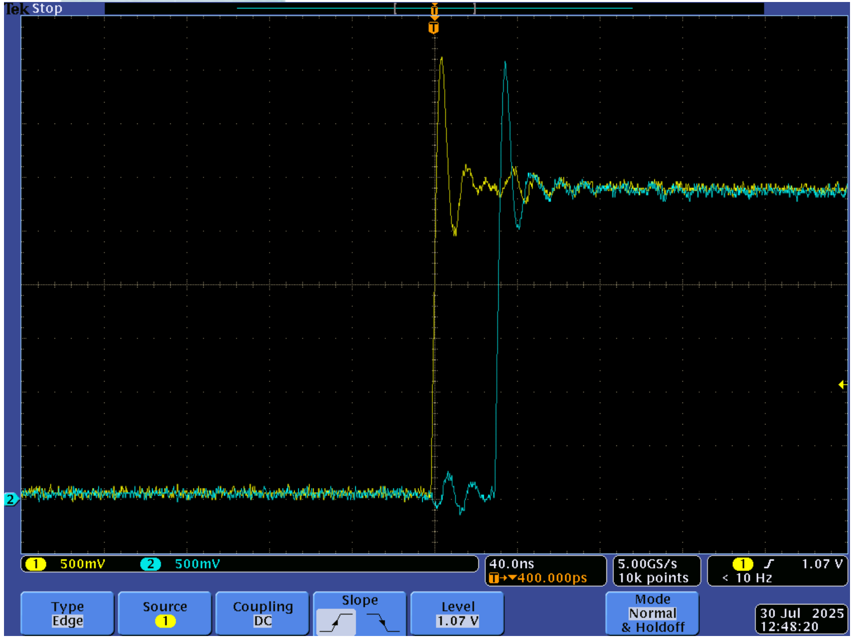


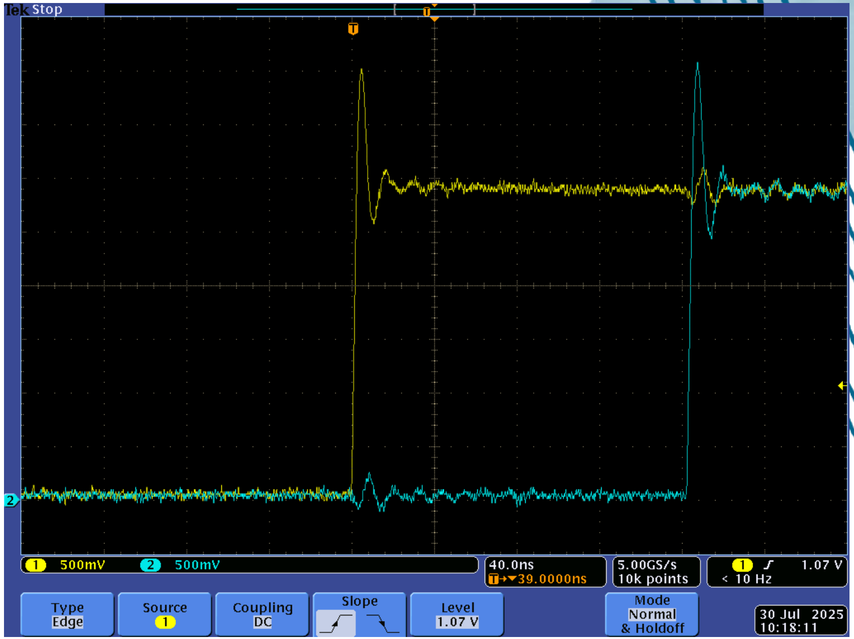
This plot shows the GPS module-4 PPS pulse arrives 62 ns after module 3.



Here the GPS antennas antenna-cables were connected to their receivers; the PPS signals were connected to the Tek DPO4104 oscilloscope inputs using 11.5 cm unshielded jumper wires; 1 MOhm terminations were used. The edge trigger is on Channel 1 GPS module 3; ch2 is GPS module 4. For three of the four GPS modules tested their pulse arrival times varied by as much as +/- 62 ns relative to the trigger on module 3. Module 1’s arrival time was about 300 ns after module 3’s.

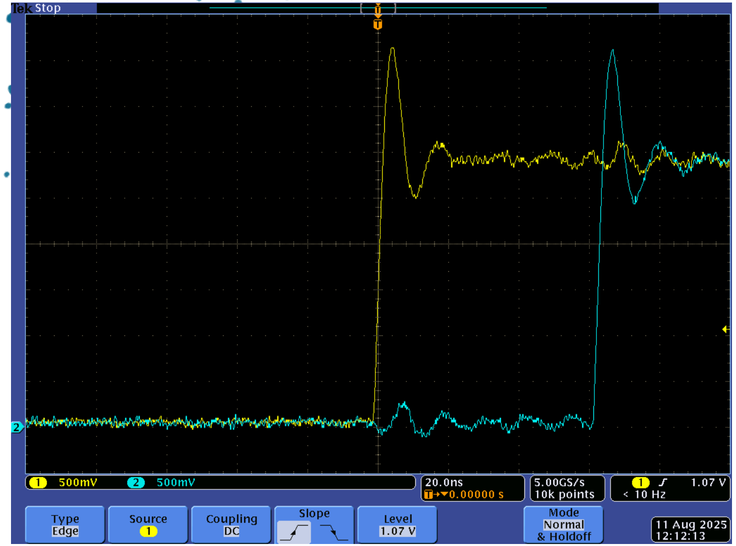
These plots show changing the GPS antenna could have increased the PPS pulse arrival time by 130 ns.

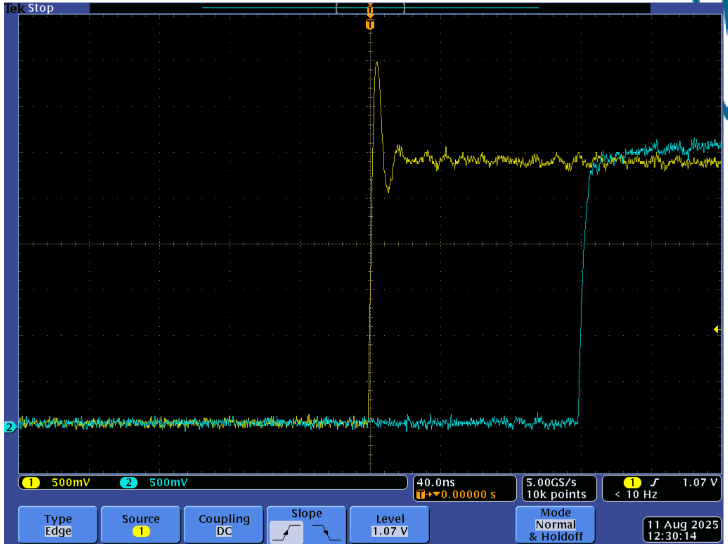




In these plots the trigger is on ch1 GPS receiver module 3, and ch2 is GPS module 4. For both receivers the 16 foot antenna-cables were used, and a 11.5 cm jumper wire between PPS and oscilloscope. In the right plot we changed the GPS antenna on module 4 ch 2, and see 130 ns more of a delay. It is hard to tell how much of this additional 130 ns is attributed to changing the antenna since the pulse arrival time typically varies by +/- 20 to +/- 60 ns from one pulse to the next.

These plots show adding cable between the GPS PPS output and oscilloscope increases the delay in pulse arrival by about 1.5 ns per foot of cable.

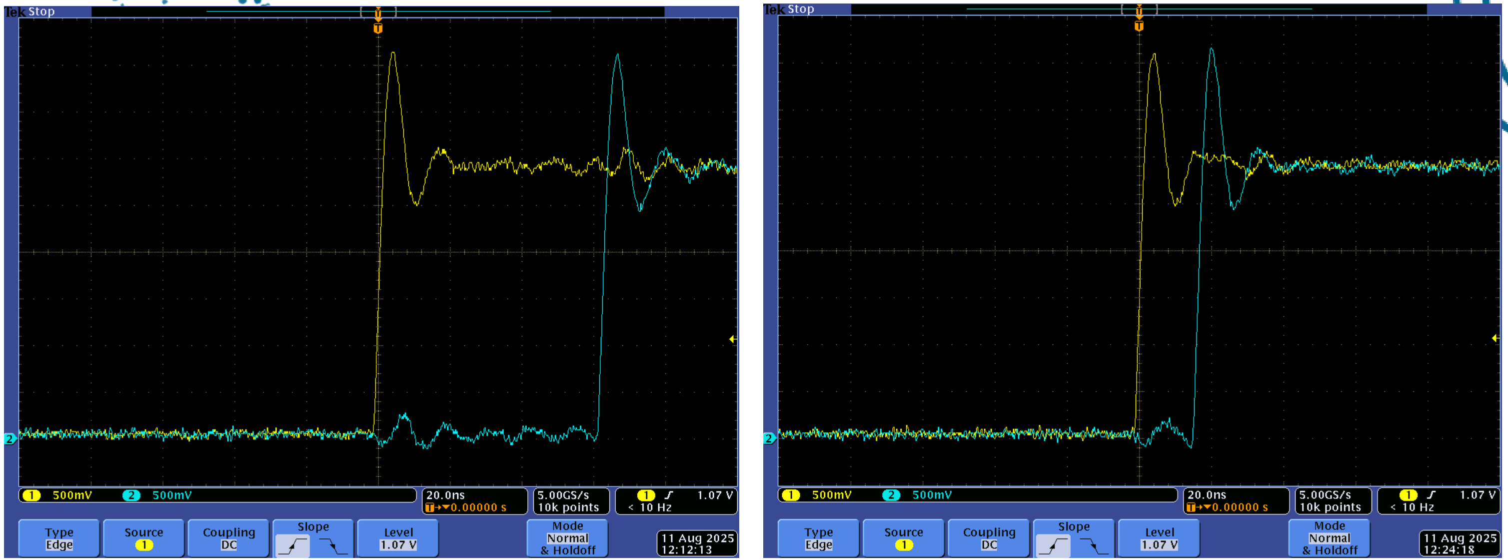




In the above plots ch1, the trigger channel, is module 3, and ch2 module 4; both receivers' were connected to the oscilloscope using 11.5 cm unshielded jumper wires. On the left plot both antennas were connected to their receivers with 16 foot antenna-cables and we see the Ch2 module 4 PPS arrives 60 ns after ch 1; but this delay time jumped around the trigger by +/- 60 ns. In the right plot the 11.5 cm wire between module 4 and oscilloscope was replaced with a 50 foot 50 Ohm cable, and we see ch2 now arrives 120 ns after the trigger (the overshoot on ch 2 appeared later along the trace due to travel time down the cable). A 50 feet cable is expected to introduce about a 75 ns delay at ⅔ the speed of light, or 1.5 nano sec per foot:

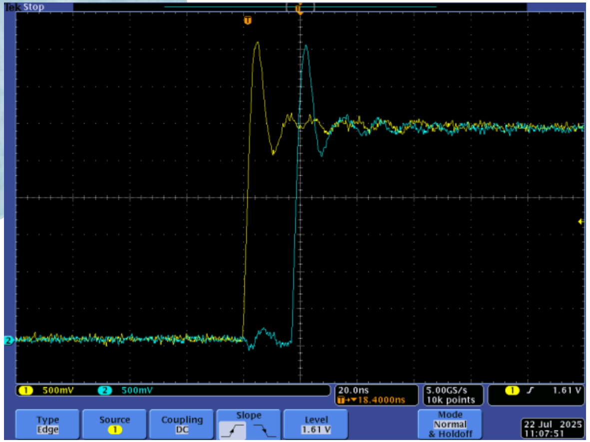
$$\Delta t = \frac{\Delta x}{V} \qquad \frac{1ft * \frac{1m}{3.28ft}}{2/3C} \approx 1.5ns$$

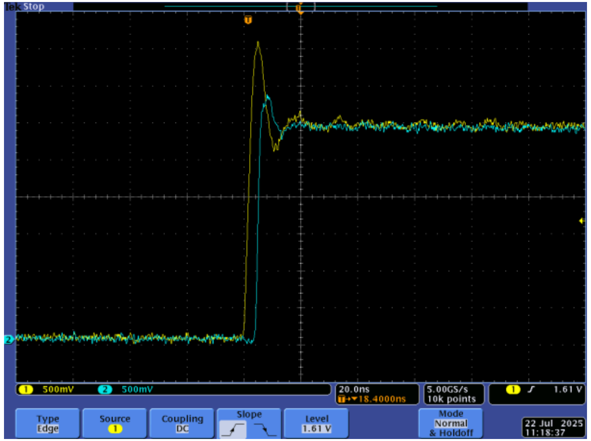
These plots show there is no time delay added to the PPS pulse when adding a 50 foot cable between the antenna and GPS receiver.



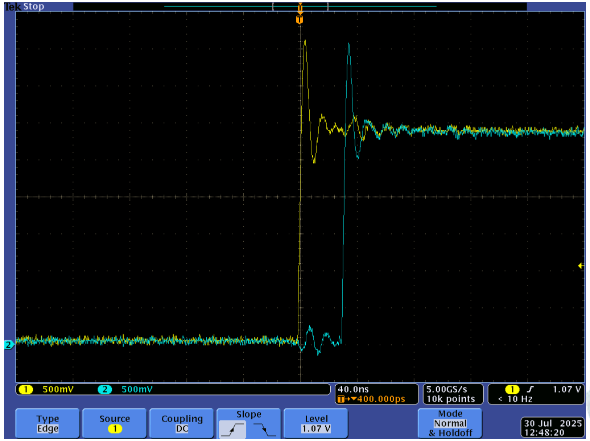
In these plots ch1, the trigger channel, is the PPS from module 3, and ch2 is from module 4. Both receivers' PPS pins were connected to the oscilloscope inputs using 11.5 cm unshielded jumper wires. In the left plot both antennas were connected to their receivers with 16 foot antenna-cables and we see ch2 module 4 arrives 60 ns later (this time jumped around the trigger by +/- 60 ns). In the right plot a 50 foot 50 Ohm cable was added to the 16 ft antenna-cable to module 4 (ch 2), and we see the pulse arrives 16 ns after the trigger. In conclusion, there was no time delay introduced by adding the longer cable between antenna and GPS receiver.

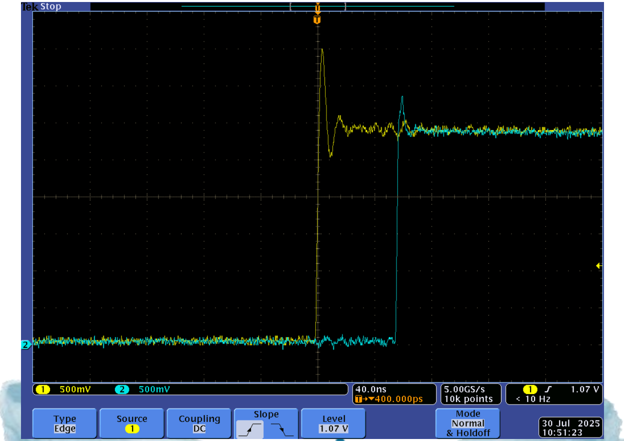
These plots show using shielded wire between the PPS output and oscilloscope on ch 2 removes most of the overshoot and a lot of the ripple noise





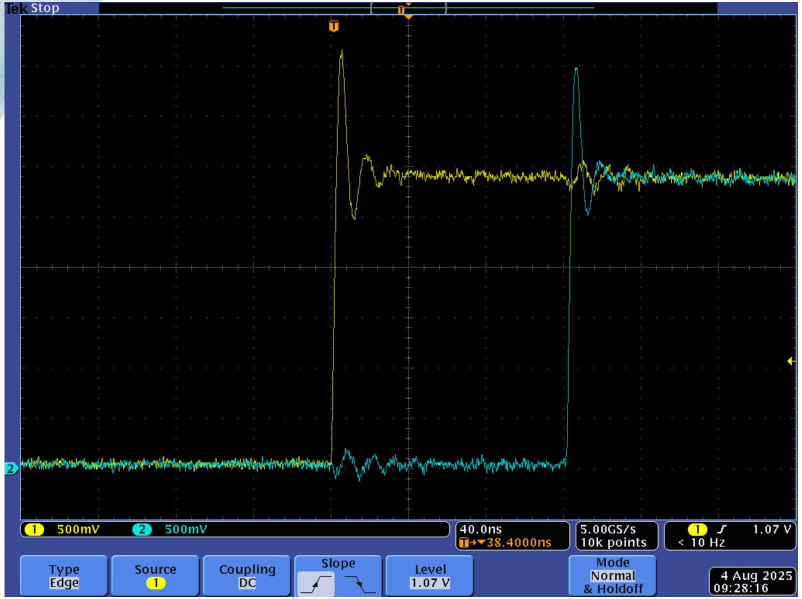
In the two plots to the left ch1 is the trigger on module 3, and ch2 is module 2. In the first plot both receivers have the 11.5 cm unshielded jumper wire between PPS and oscilloscope; in the second plot module 2 (ch 2) has a 10 cm shielded wire.

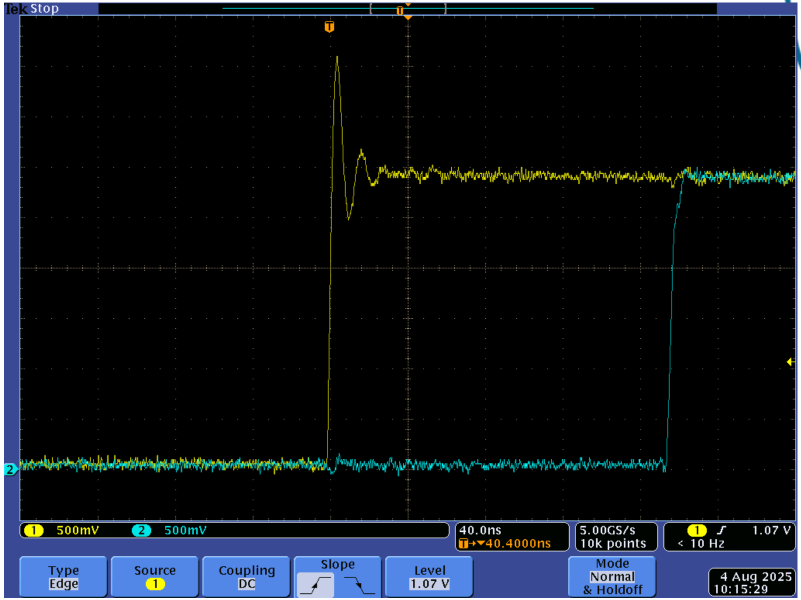




In the plots to the left ch1 is the trigger on module 3, and ch2 is module 4. In the first plot both receivers have the 11.5 cm unshielded jumper wire between PPS and oscilloscope; in the second plot module 4 (ch 2) has a 10 cm shielded wire.

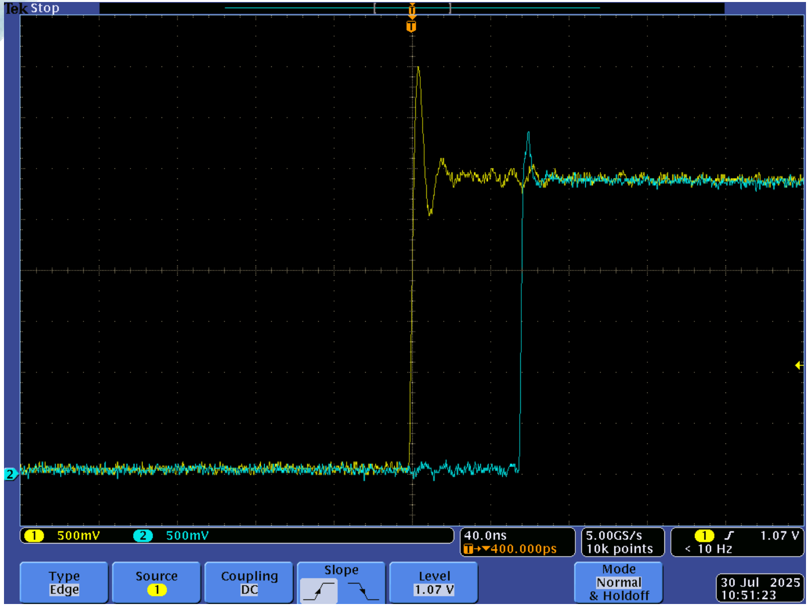
These plots show adding a series 100 Ohm resistor at the output of the PPS, before the unshielded jumper wire, eliminates the overshoot, and the ripple from the low and high parts of the trace.

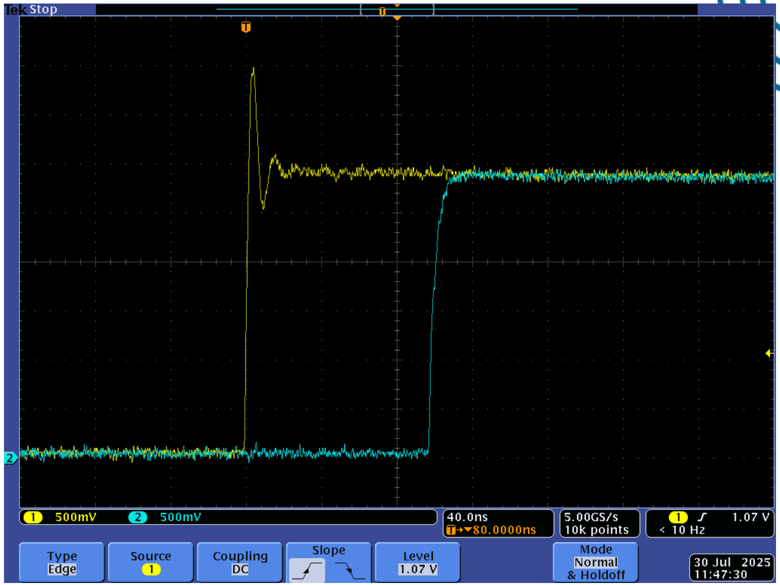




In the plots ch1 is module 3, and ch2 is module 1. Both have a 11.5 cm unshielded jumper wire between the PPS and oscilloscope In the right plot a series 100 Ohm resistor was added at the PPS output before the jumper wire. There is a 55 ns longer delay in the pulse arrival from 120 ns to 175 ns; however it is unclear if adding the resistor caused a delay because as previously noted the delay on the module 1 pulse can be as high as 300 ns.

These plots show adding a series 100 Ohm resistor at the output of the PPS, before the shielded wire, eliminates the overshoot, and ripple from the low and high parts of the trace, but rounds the rising edge of the pulse



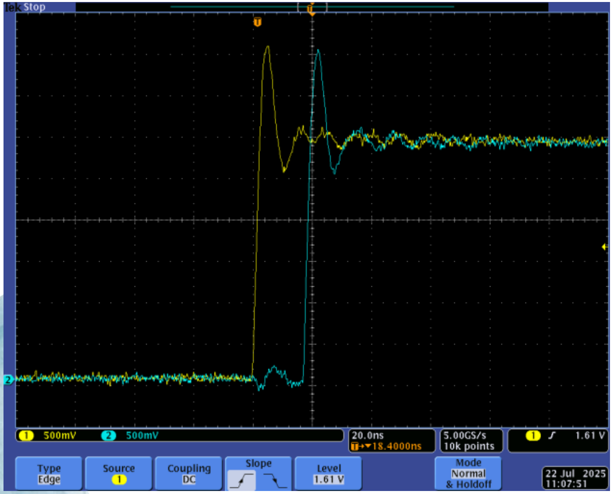


In the two plots ch1 is module 3, and ch2 is module 4. In the left plot there is a 10 cm shielded wire between the PPS and oscilloscope; in the right plot a series 100 Ohm resistor was added to the PPS output before the shielded wire, removing the overshoot and ripple.

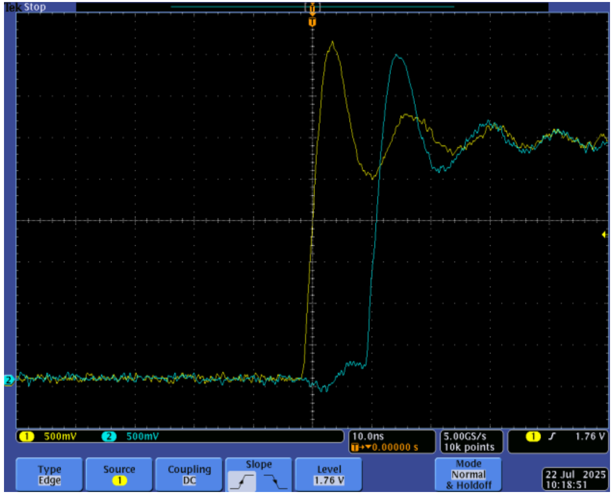
These plots demonstrate the longer the unshielded wire between the PPS and oscilliscope the worse the ripple noise and overshoot. The wire length was changed on receiver module 2 (ch 2), while the unshielded wire length on module 3 (ch 1) was constant at 11.5 cm. Since the module 3 trace on ch 1 becomes more noisy when we change the wire on module 2, we conclude that RF noise is coupling from module 2 over to module 3 (no 100 Ohm resistor was used on any of these measurements)

Ch.1 - GPS Module No.3 PPS

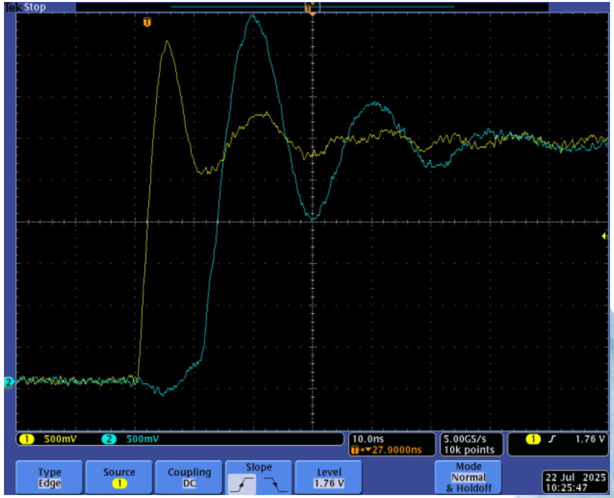
Ch.2 - GPS Module No.2 PPS



11.5 cm unshielded wire on ch2



17.5 cm unshielded wire on ch2

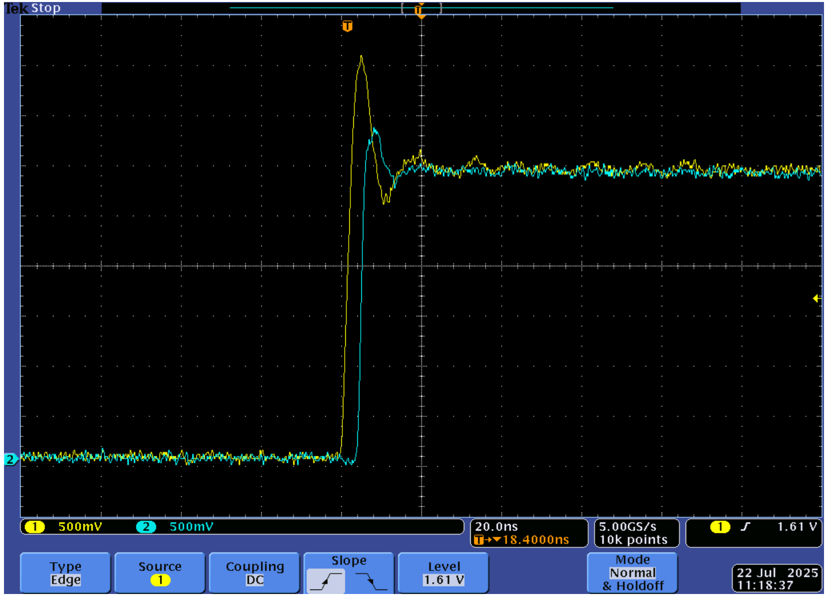


32 cm unshielded wire on ch2

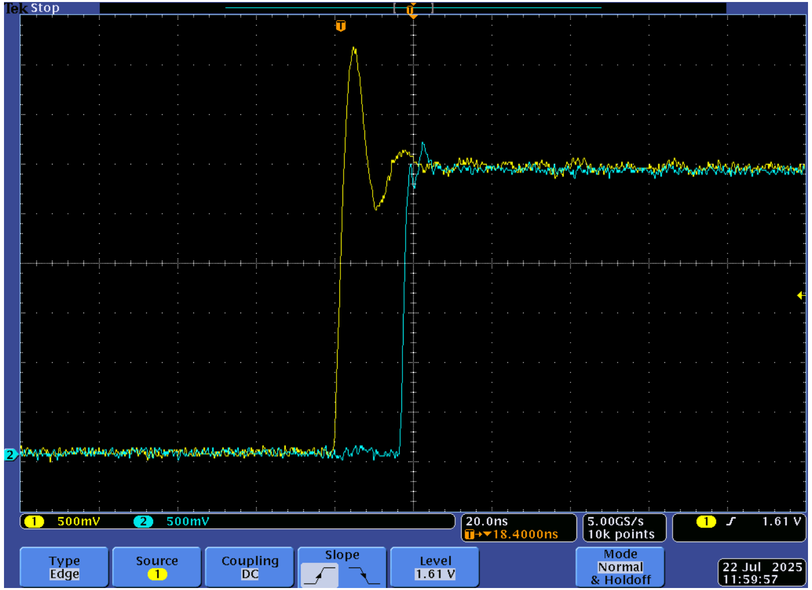
These plots show the shielded wire between the PPS and oscilloscope (on module 2, ch 2) reduced the overshoot; the 20 cm length resulted in a smaller overshoot than the 10 cm length. In both plats an unshielded 11.5 cm was used on module 3 (ch 1) between the PPS and oscilloscope (no 100 Ohm resistor was used on any of these measurements).

Ch.1 - GPS Module No.3 PPS

Ch.2 - GPS Module No.2 PPS

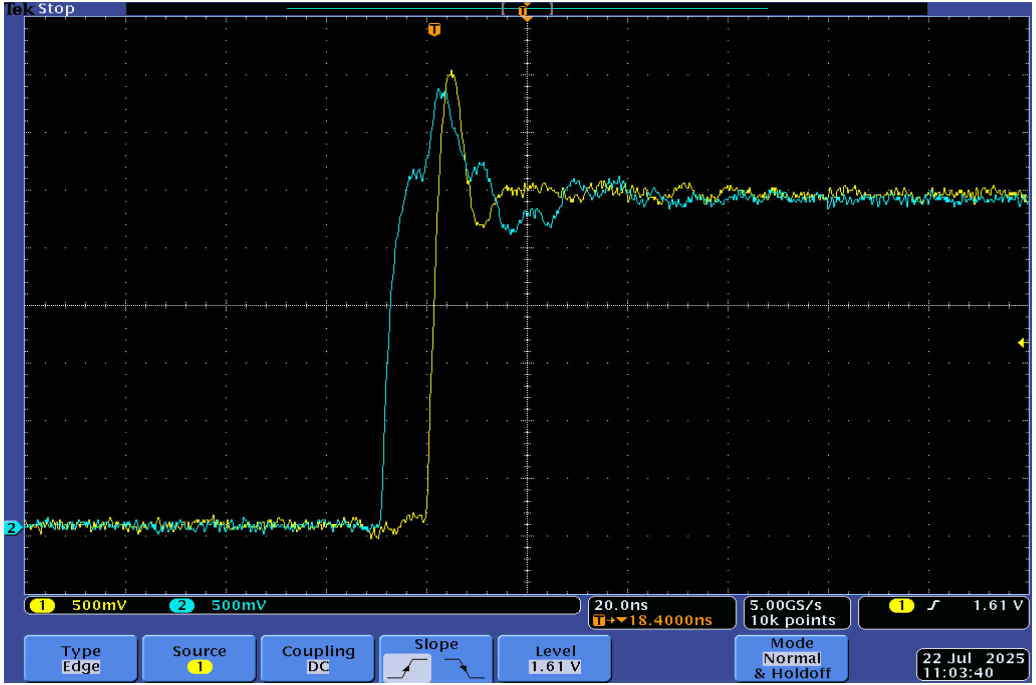


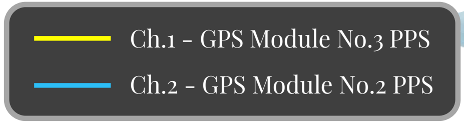
10 cm shielded wire on ch 2



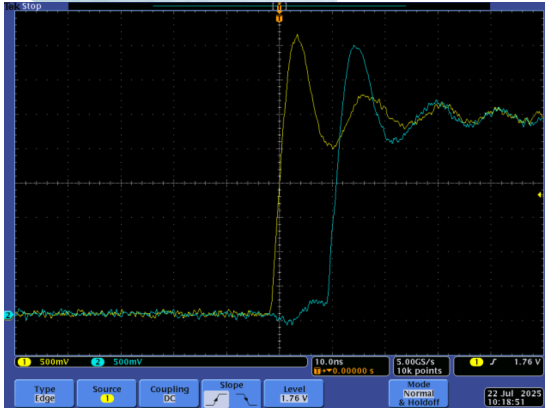
20 cm shielded wire on ch 2

This plot shows the result in using a 30.75 inch 50 Ω shielded coaxial cable + the 11.5cm unshielded jumper wire on module 2, ch 2.
Ch 1 module 3 had a 11.5 cm unshielded jumper wire.



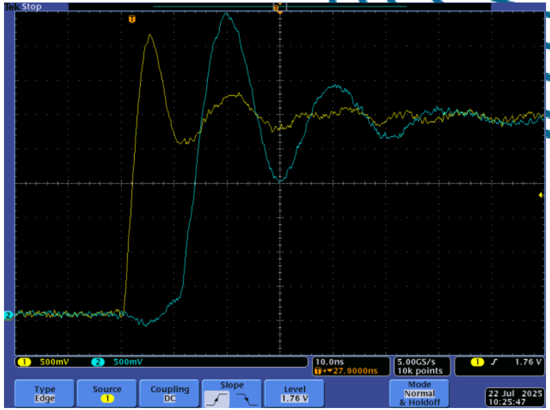


Results when using unshielded jumper wires between PPS and oscilloscope (no resistor used)

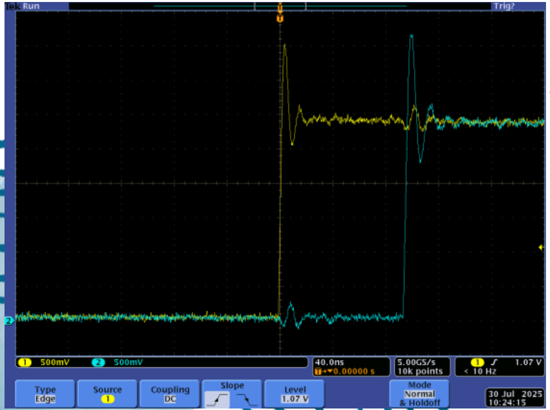


11.5cm vs 17.5cm Jumper Wires ↲

11.5cm vs 32cm Jumper Wires ↳

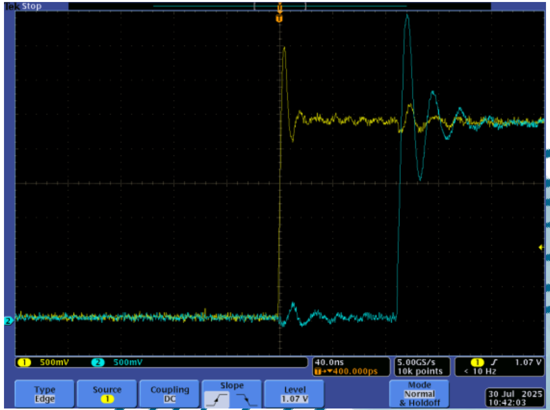


GPS Module 3 (ch1) vs module 2 (ch2)



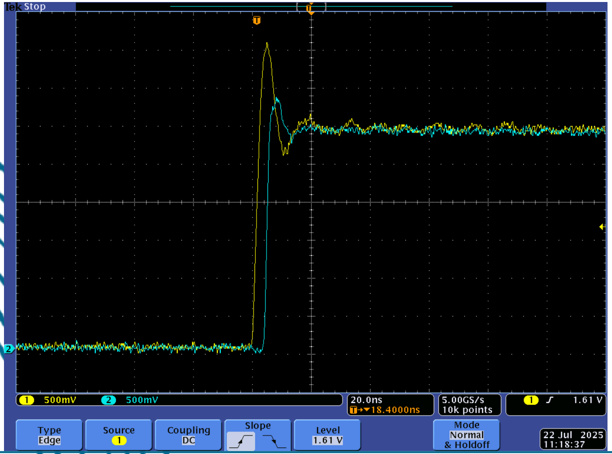
11.5cm vs 17.5cm Jumper Wires ↲

11.5cm vs 32cm Jumper Wires ↳



GPS Module 3 (ch 1) vs module 4 (ch 2)

Results when using shielded wire vs. unshielded wire between PPS and oscilloscope (no resistor used)

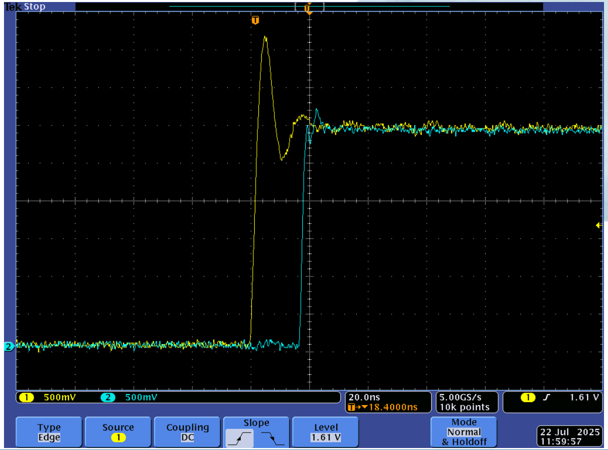


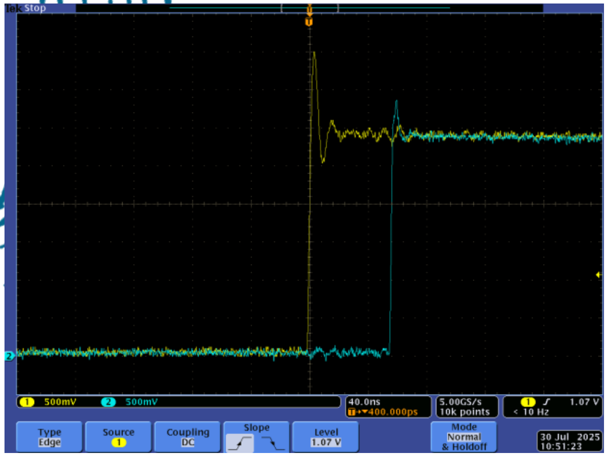
Module 3 (ch 1) unshielded 11.5cm wire
Module 2 (ch 2) 10cm shielded wire

↲

Module 3 (ch 1) unshielded 11.5cm wire
Module 2 (ch 2) 20cm shielded wires

↳



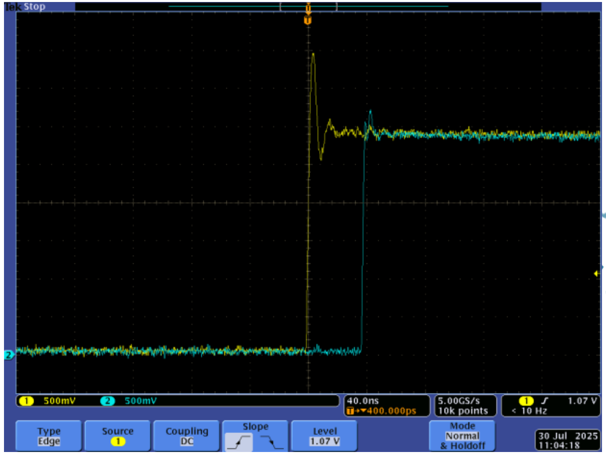


Module 3 (ch 1) unshielded 11.5cm wire
Module 4 (ch 2) 10cm shielded wire

↲

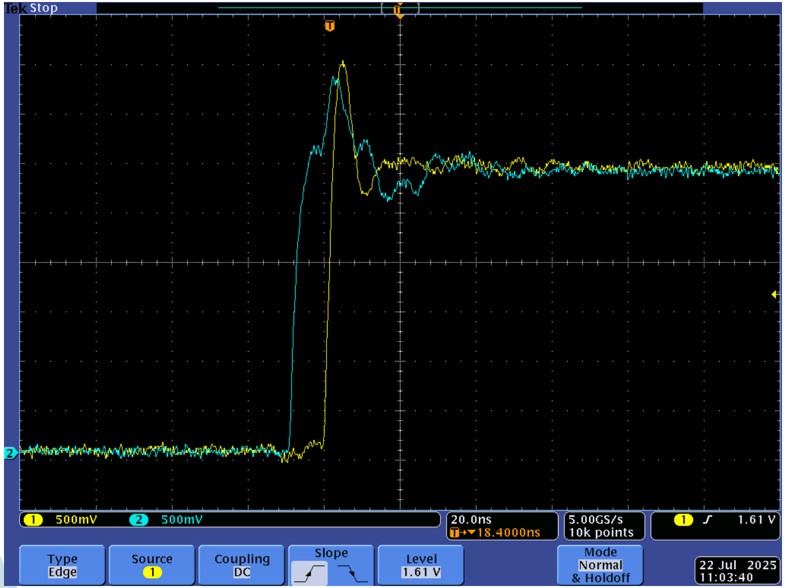
Module 3 (ch 1) unshielded 11.5cm wire
Module 4 (ch 2) 20cm shielded wires

↳

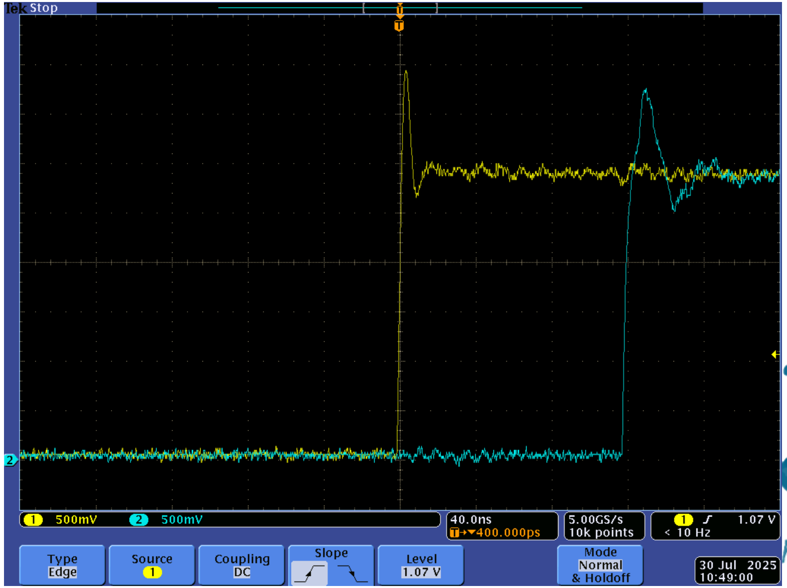


Results when using a 50 Ω coax shielded cable + 11.5cm unshielded jumper wire
(no 100 Ohm resistor used)

Module 3 (ch 1) unshielded 11.5 cm jumper wire
Module 2 (ch 2) shileded 50 Ohm coax + 11.5 cm unshielded wire



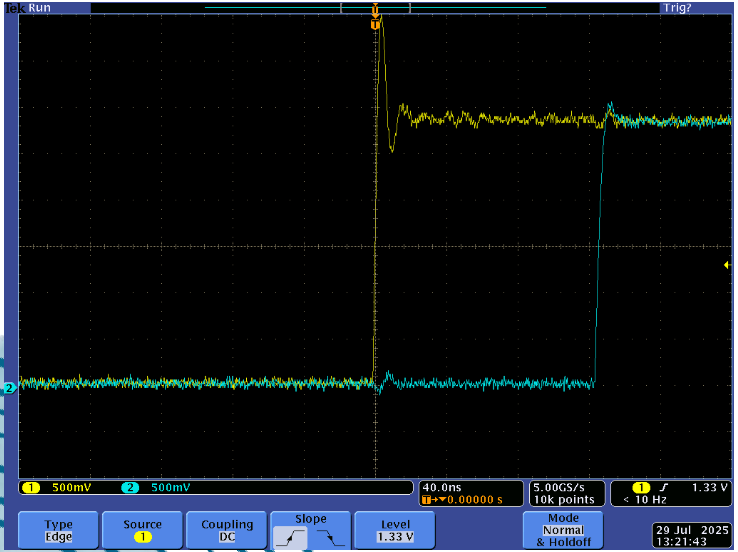
Module 3 (ch 1) unshielded 11.5 cm jumper wire
Module 4 (ch 2) shileded 50 Ohm coax + 11.5 cm unshielded wire



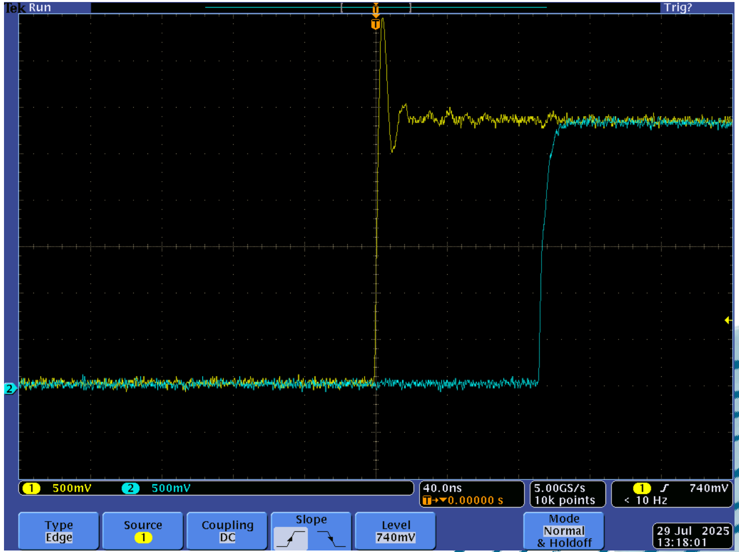
Results when using a 100 ohm resistor between the GPS PPS and oscilloscope, GPS modules 3 vs 2

Ch.1 - GPS Module No.3 PPS
Ch.2 - GPS Module No.2 PPS

Module 3 (ch 1) 11.5cm unshielded jumper Wire
Module 2 (ch 2) 100 Ohm resistor plus 11.5 cm unshielded jumper Wire

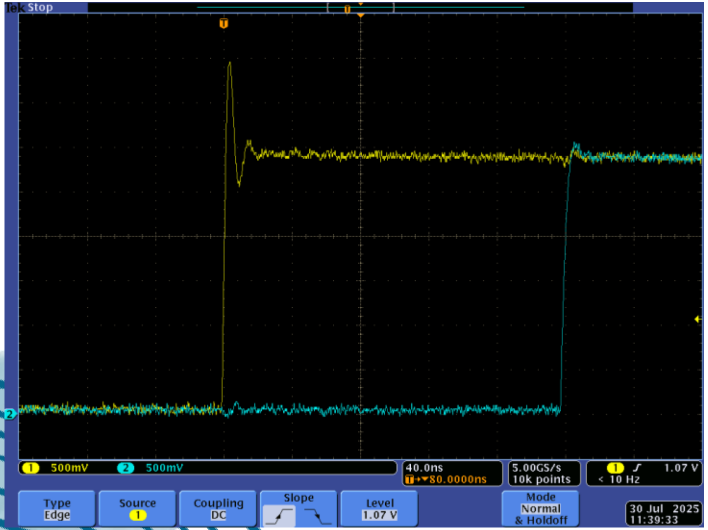


Module 3 (ch 1) 11.5cm unshielded jumper Wire
Module 2 (ch 2) 100 Ohm resistor plus 10 cm shielded jumper Wire



Results when using a 100 ohm resistor between the GPS PPS and oscilloscope, GPS modules 3 vs 4

Module 3 (ch 1) 11.5cm unshielded jumper wire.
Module 4 (ch 2) 100 Ohm resistor plus 11.5 cm unshielded jumper Wire



Module 3 (ch 1) 11.5cm unshielded jumper Wire
Module 4 (ch 2) 100 Ohm resistor plus 10 cm shielded jumper Wire